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RESISTANCE TRANING PROTOCOLS PROMOTE STRENGTH INCREASE WITHOUT MORPHOLOGICAL CHANGES

PROTOCOLOS DE TREINAMENTO DE FORÇA PROMOVEM AUMENTO DA FORÇA SEM ALTERAÇÕES MORFOLÓGICAS

PROTOCOLOS DE ENTRENAMIENTO DE FUERZA PROMUEVEN AUMENTO DE LA FUERZA SIN ALTERACIONES MORFOLÓGICAS

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Andressa Prata Leite Damiani[1] (Physical Education Professional)
Leonardo Carvalho Caldas[2] (Physical Education Professional)
Alexandre Barroso Melo[2] (Physical Education Professional)
Catarina Denise Entringer Contreiro[1] (Nutritionist)
Wagner Muller Estevam[2] (Physical Education Professional)
Breno Valentim Nogueira[3] (Physiotherapist)
Lucas Guimarães Ferreira[1,2] (Physical Education Professional)
André Soares Leopoldo[1,2] (Physical Education Professional)
Ana Paula Lima Leopoldo[1,2] (Physical Education Professional)

1. Universidade Federal do Espírito Santo (UFES), Centro de Ciências da Saúde, Graduate Studies Program in Nutrition and Health, Vitória, ES, Brazil.
2. Universidade Federal do Espírito Santo (UFES), Centro de Educação Física e Desportos, Physical Education Graduate Studies Program, Vitória, ES, Brazil.
3. Universidade Federal do Espírito Santo (UFES), Centro de Ciências da Saúde, Department of Morphology, Vitória, ES, Brazil.

Correspondence:
Ana Paula Lima Leopoldo. Department of Sports, Center of Sports and Physical Education, Universidade Federal do Espírito Santo, Vitória, ES, Brazil. 29075-910. ana.leopoldo@ufes.br

ABSTRACT

Introduction: Resistance training (RT) has been related to increased protein synthesis, and in the myocardium it triggers morphological adaptations that result in improved cardiac contractility. In skeletal muscle, RT promotes an improvement in functional capacity and in sarcopenia caused by aging. However, the efficacy of this training method in the cardiac and skeletal systems has not yet been clarified. Objective: To investigate the effect of different vertical ladder RT protocols on cardiac and skeletal structure and morphology. Materials and Methods: Wistar rats (n = 28) were randomized into four groups: sedentary (C); RT protocol with 4 to 9 climbs, 3 sessions/week, 120 second interval and intensity of 50% to 100% of the maximum load (ML) with progressive addition of 30 g (RT1); RT protocol with 4 to 5 climbs, 3 sessions/week, 60 second interval and intensity of 50% to 100% of the ML, where a 30 g overload was added in the 5th climb (RT2); RT protocol with 4 to 5 climbs, 5 sessions/week, 60 second interval and intensity of 50% to 100% of the ML; the animals that completed the 4th climb underwent the 5th climb with 100% ML plus 30 g (RT3). RT protocols were performed for 9 weeks with a duration of 30 to 45 minutes/day. The nutritional profile and cardiac/skeletal muscle morphology were evaluated along with the cross sectional area and collagen fraction. Results: RT did not promote adaptations in cardiac and musculoskeletal structure and morphology, nor was it able to reduce body weight and body fat deposits. However, RT brought about an increase in absolute and relative strength. Conclusion: Vertical ladder RT protocols, regardless of weekly frequency, lead to increased muscle strength without cardiac and skeletal structural adaptations. ***Level of evidence I, Therapeutic studies - Investigating treatment results.***

Keywords: Resistance training; Heart; Skeletal muscle.

RESUMO

Introdução: O treinamento de força (TF) tem sido relacionado ao aumento da síntese proteica, sendo que no miocárdio desencadeia adaptações morfológicas que resultam na melhora da contratilidade cardíaca. No músculo esquelético, o TF promove melhora da capacidade funcional e da sarcopenia causada pelo envelhecimento. Todavia, a eficácia dessa modalidade de treinamento nos sistemas cardíaco e esquelético ainda precisa ser esclarecida. Objetivo: Investigar o efeito de diferentes protocolos de TF em escada vertical sobre a estrutura e morfologia cardíaca e esquelética. Materiais e Métodos: Ratos Wistar (n=28) foram randomizados em quatro grupos: sedentário (C); protocolo de TF com 4 a 9 subidas, 3 sessões/semana, intervalo de 120 segundos e intensidade de 50% a 100% da carga máxima (CM) com adição progressiva de 30 g (TF1); protocolo de TF com 4 a 5 subidas, 3 sessões/semana, intervalo de 60 segundos e intensidade de 50% a 100% da CM, sendo que na 5º subida foi adicionada sobrecarga de 30 g (TF2); protocolo de TF com 4 a 5 subidas, 5 sessões/semana, intervalo 60 segundos e intensidade de 50% a 100% da CM; os animais que completaram a 4ª subida foram submetidos à 5ª subida com 100% da CM acrescido de 30 g (TF3). Os protocolos de TF foram realizados por 9 semanas com duração de 30 a 45 minutos/dia. O perfil nutricional, a morfologia muscular cardíaca e esquelética, assim como a área seccional transversa e fração de colágeno foram avaliados. Resultados: O TF não promoveu adaptações na estrutura e morfologia cardíaca e musculoesquelética, assim como não foi capaz de reduzir o peso e os depósitos de gordura corporal. Entretanto, o TF ocasionou aumento da força absoluta e relativa. Conclusão: Os protocolos de TF em escada vertical, independentemente da frequência semanal, levam a um aumento da força muscular sem adaptações estruturais cardíacas e esqueléticas. ***Nível de evidência I, Estudos terapêuticos – Investigação dos resultados do tratamento.***

Descritores: *Treinamento de força; Coração; Músculo esquelético.*

RESUMEN

Introducción: El entrenamiento de fuerza (EF) ha sido relacionado al aumento de la síntesis proteica, siendo que en el miocardio desencadena adaptaciones morfológicas que resultan en la mejora de la contractilidad cardíaca. En el músculo esquelético, el EF promueve mejora de la capacidad funcional y de la sarcopenia causada por el envejecimiento. No obstante, la eficacia de esa modalidad de entrenamiento en los sistemas cardíaco y esquelético aún necesita ser esclarecida. Objetivo: Investigar el efecto de diferentes protocolos de EF en escalera vertical sobre la estructura y morfología cardíaca y *esquelética. Materiales y Métodos: Fueron seleccionados aleatoriamente ratones Wistar (n=28) en cuatro grupos: sedentario (C); protocolo de EF con 4 a 9 subidas, 3 sesiones/semana, intervalo de 120 segundos e intensidad de 50% a 100% de la carga máxima (CM) con agregado progresivo de 30 g (EF1); protocolo de EF con 4 a 5 subidas, 3 sesiones/semana, intervalo de 60 segundos e intensidad de 50% a 100% de la CM, siendo que en la 5ª* subida *fue agregada sobrecarga de 30 g (EF2); protocolo de EF con 4 a 5 subidas, 5 sesiones/semana, intervalo 60 segundos e intensidad de 50% a 100% de la CM; los animales que completaron la 4ª subida fueron sometidos a la 5ª subida con 100% de la CM con incremento de 30 g (EF3). Los protocolos de EF fueron realizados por 9 semanas con duración de 30 a 45 minutos/día. Fueron evaluados el perfil nutricional, la morfología muscular cardiaca y esquelética, así como el área seccional transversa y fracción de colágeno. Resultados: El EF no promovió adaptaciones en la estructura y morfología cardíaca y musculoesquelética, así como no fue capaz de reducir el peso y los depósitos de grasa corporal. Entretanto, el EF ocasionó un aumento de la fuerza absoluta y relativa. Conclusión: Los protocolos de EF en escalera vertical, independientemente de la frecuencia semanal, llevan a un aumento de la fuerza muscular sin adaptaciones estructurales cardíacas y esqueléticas.* ***Nivel de Evidencia I, Estudios terapéuticos - Investigación de los resultados del tratamiento.***

Descriptores: *Entrenamiento de resistencia; Corazón, Músculo esquelético.*

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INTRODUCTION

Research has shown that chronic exercise training is associated as a useful tool for promoting cardiac and musculoskeletal adaptations[1-3] through physiological, biochemical and morphofunctional changes.[4-6] These adaptations occur progressively as training is performed systematically and regularly, a condition that contributes to improved performance.[7]

Resistance training (RT) has been used as a non-pharmacological form of treatment in humans and experimental models using the vertical ladder apparatus, as this makes it possible to mimic the training applied in humans.[7-12]

RT is defined as a set of exercises performed against an opposing force aimed at improving physical functionality, increasing strength and mass.[13] Researchers have also indicated improved body composition and reduced adipocyte area after intervention with RT in obese animals.[7,14] RT is also related to increased protein synthesis and cardiac and musculoskeletal muscle hypertrophy.[4,15]

In the myocardium, the physiological stimulus of RT triggers morphological adaptations that result in improved cardiac contractility.[16] Moreover, in musculoskeletal tissue there is an improvement in functional capacity and a reduction of sarcopenia.[17] However, there is still a shortage of studies mimicking in experimental animals the progressive RT performed in humans, both in training variables and in consequent adaptations.[7,11] Thus, the purpose of the study was to investigate the effect of different RT protocols on cardiac and skeletal tissue structural morphology.

MATERIALS AND METHODS

Twenty-eight Wistar rats (200-250g), aged 30 days, supplied Animal Quarters of the Center for Health Sciences of Universidade Federal of Espírito Santo (UFES) were used in the study. The animals were kept in collective cages, in a controlled environment with temperature of 24 ± 2ºC, relative humidity of 55 ± 5% and a 12-hour light-dark cycle. The experimental procedures were conducted according to the "Guide for the Care and Use of Laboratory Animals", and were approved by the UFES Animal Ethics Committee under protocol 1036-2013.

The rats were acclimatized for seven days, then randomly assigned to four experimental groups: 1) Sedentary (C); 2) Resistance Training originally developed and applied by Hornberger and Farrar[11] (RT1); 3) Resistance Training with weekly frequency of three days (RT2) and; 4) Resistance Training with weekly frequency of five days (RT3). The resistance training protocols (RT2 and RT3) were adapted from RT1. The animals received standard feed (Agroceres®, Rio Claro, Brazil) and water was offered *ad libitum*.

The trained animals were initially allowed three nonconsecutive days to become familiar with the environment and the apparatus used for resistance training; after 24h, the rats underwent the maximum load test (MLT).[7] The MLT consisted of climbing the ladder once with a load equivalent to 75% of body weight and a two minute interval. A weight of 30 g was added to the previous load in each set performed. Failure was defined when animals were unable to climb the ladder, remaining static and unstable even after dorsal and caudal stimulation.

The highest load carried was considered the maximum load (ML), which was used to prescribe training intensities. To monitor the development of strength and ML values, a retest was conducted at the end of the training protocol, considering the first set with 100% of the load carried in the last session of the training period and a two minute interval. A 30 g weight was added to the previous load in each set.

RT, adapted from Hornberger and Farrar,[11] was performed with a vertical ladder apparatus (1.1 m high, 0.18 m wide, with rungs set 2.0 cm apart, at an angle of 80°) and a box at the top measuring 20cm x 20cm x 20cm. The load used in the three training protocols of resistance was fastened to the proximal portion of the animal's tail.

After the familiarization period, the rats underwent three different resistance training protocols on a vertical ladder for nine weeks, between three and five days per week, with an average duration of 30 to 45 minutes/day. RT1 consisted of four to nine climbs, three sessions/week, a two minute interval and intensity of 50%, 75%, 90% and 100% ML, with progressive addition of 30 g between the 5th and 9th climbs. The RT2 protocol consisted of four to five climbs, three sessions/week, a one minute interval and intensity of 50%, 75%, 90% and 100% ML, with the addition of a 30 g overload in the 5th climb. The animals in the RT3 protocol climbed the ladder four to five times, five sessions/week, with a one minute interval and intensity of 50%, 75%, 90% and 100% ML, with the addition of a 30 g overload up to the fifth set.

Strength performance was determined by the maximum load used, presented in absolute (g) and relative load (absolute load/body weight). Under dynamic conditions such as ladder RT, normalization of the maximum load carried by body weight represents an important indicator of functional performance.[18]

The body weight of the animals was measured weekly and the amount of body fat determined on the base of epididymal, retroperitoneal and visceral fat deposits. The adiposity index was calculated by dividing the sum of fat deposits by the final body weight multiplied by 100.

The rats were anesthetized intraperitoneally with ketamine hydrochloride (50 mg/kg) and xylazine hydrochloride (10 mg/kg) and euthanized.

After median thoracotomy, adipose tissue, cardiac and skeletal muscle samples were dissected, weighed and stored. The tibia was also dissected and its length was measured using an analog caliper.

Cardiac morphology was determined by the weight of the heart, left and right ventricles (LV and RV), atrium, and respective ratios in respect to tibial length. Skeletal morphology was represented by the total weight of the soleus, plantaris and biceps muscles.

LV samples were collected for analysis of the cross-sectional area (CSA) and quantification of the myocardial collagen volume fraction. Samples were soaked in 4% paraformaldehyde solution, pH 7.4, transferred to 70% ethanol solution and embedded in paraffin blocks. The histological sections were then stained and mounted on a slide with hematoxylin and eosin (HE). CSA images were obtained by microscope (AX70, Olympus Optical CO, Japan) using 40X objective. Area calculation was determined by measuring 30 to 50 cells by LV with visible, centralized and rounded nucleus.

To determine myocardial collagen, LV samples were transferred to 70% ethanol, then embedded in paraffin blocks and stained with picrosirius red. Quantitation was determined by 30 to 40 fields per fragment using a microscope with 40X objective. The analyses were performed with the assistance of the analysis program (ImagePro-plus, Media Cybernetics, Maryland, USA).

Biceps muscle fragments were collected post mortem, soaked in 4% paraformaldehyde solution, pH 7.4, and transferred to 70% ethanol solution. The samples were embedded in paraffin blocks and the slides stained with HE solution. To calculate the musculoskeletal CSA, 500 fibers per tissue per animal were measured.

Statistical analysis

Data distribution was performed using the Kolmogorov-Smirnov normality test. Results were expressed as mean and standard deviation and/or median and interquartile range according to adherence. One factor analysis of variance (ANOVA) was used, supplemented by the Bonferroni or Holm-Sidak multiple comparison test. Statistical programs were SigmaStat 3.5 and Graphpad Prism 6. The significance level was 5%.

RESULTS

The three RT protocols used did not significantly alter initial and final body weight, body weight gain, epididymal, retroperitoneal and visceral fat deposits, or total body fat and adiposity index (Table 1). In addition, the percentage of body weight gain was higher in RT1 than in RT2 ($p = 0.03$), representing an increase of 37.7% in this parameter (*data not shown*).

Table 1. General characteristics of the experimental groups.

	Groups			
Variables	C	RT1	RT2	RT3
IBW (g)	255 ± 37	220 ± 67	237 ± 38	253 ± 42
FBW (g)	465 ± 69	457 ± 58	403 ± 67	470 ± 75
Body weight gain (g)	210 ± 45	237 ± 57	167 ± 47	216 ± 37
Epididymal fat (g)	4.51 ± 1.59	4.81 ± 2.57	3.31 ± 1.31	4.84 ± 2.52
Retroperitoneal fat (g)	11.9 ± 4.3	11.9 ± 4.6	8.44 ± 2.09	13.0 ± 5.3
Visceral fat (g)	5.66 ± 2.42	6.61 ± 2.31	4.31 ± 1.29	6.73 ± 2.21
Total body fat (g)§	19.7 ± 9.9	21.7 ± 16.2	17.5 ± 6.1	22.2 ± 16.0
Adiposity index (%)	4.68 ± 0.99	5.01 ± 1.57	3.96 ± 0.62	5.08 ± 1.47

Values expressed in mean ± standard deviation, 7 animals per experimental group; RT: Resistance training; C: sedentary control group; RT1: RT protocol with 4 to 9 climbs, 3 sessions/week, 2-minute interval and intensity of 50% to 100% of the maximum load (ML); an overload of 30 g was added up to the 9th set; RT2: RT protocol with 4 to 5 climbs, 3 sessions/week, 60-second interval and intensity of 50% to 100% ML, with the addition of a 30 g overload up to the 5th set; RT3: RT protocol with 4 to 5 climbs, 5 sessions/week, 60-second interval and intensity of 50% to 100% ML; when the 4th set was performed, the animals underwent the 5th climb with 100% + 30 g. IBW: initial body weight; FBW: final body weight. §Data presented in median ± interquartile range. One-way ANOVA supplemented by Bonferroni post-hoc test for data with normal distribution. For nonparametric samples, they were supplemented by Holm-Sidak post-hoc test.

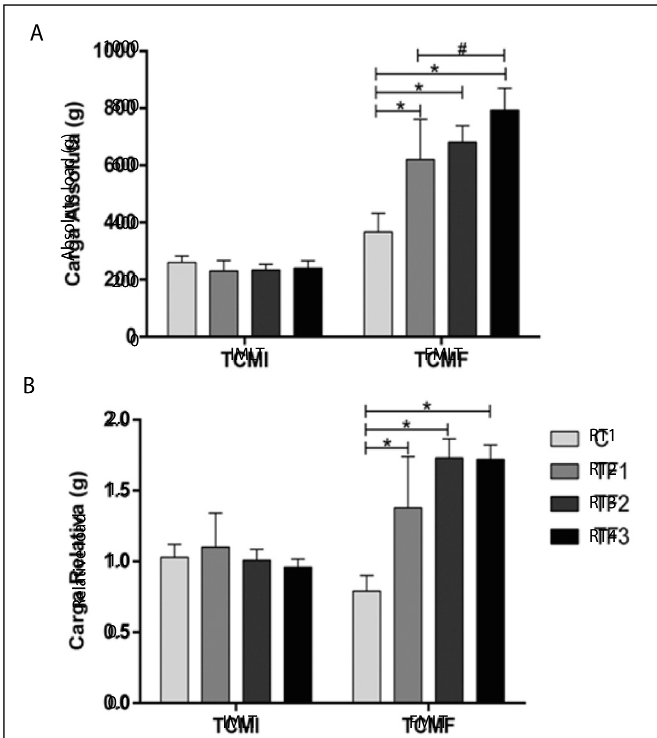
Absolute and relative pre-training loads were similar among groups (Figure 1). In the FMLT, performed after the end of the resistance training protocol, it was observed that the RT1, RT2 and RT3 groups presented high strength gain when compared to C ($p < 0.001$) (Figure 1A), representing an increase of 69%, 86% and 116% in comparison to C, respectively. Moreover, when normalized by body weight, the same result was found with an increase of 74%, 119%, and 117%, respectively (Figure 1B). RT3 presented higher absolute training load than RT1 with higher strength performance (28%) as a result (Figure 1A).

No macroscopic changes were observed in cardiac tissue and skeletal muscle, represented by the weights of the heart, LV, RV and AT and normalized by the tibial length, as well as the weight of the biceps, soleus and plantaris muscles and their respective relationship with the tibia (Table 2).

Figure 2A-C shows the histological sections of LV and skeletal muscle samples for quantification of myocyte CSA, myocardial collagen volume fraction and biceps CSA. In both microscopic analyses performed, RT performed for nine weeks did not change the cardiac and musculoskeletal structure.

DISCUSSION

The purpose of the study was to analyze the morphology and tissue structure of the cardiac and skeletal muscles under different ladder RT protocols. In this context, the ladder RT protocols do not generate cardiac and musculoskeletal tissue morphological adaptations at the optical microscopy level, yet they demonstrate the important role of RT in absolute and relative strength gain, visualized by the greater strength of the trained groups when compared to the sedentary group (C). This result highlights that RT was able to improve functional capacity based on different RT protocols, regardless of weekly frequency.



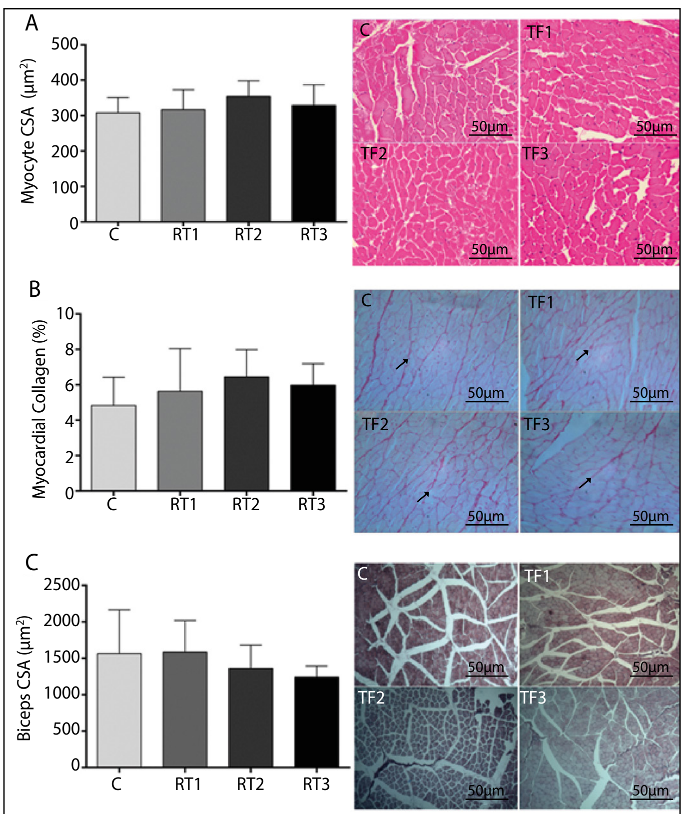
Values expressed in mean ± standard deviation; 7 animals per group; C: sedentary control group; RT1: RT protocol with 4 to 9 climbs, 3 sessions/week, 2-minute interval and intensity of 50% to 100% of the maximum load (ML); an overload of 30 g was added up to the 9th set; RT2: RT protocol with 4 to 5 climbs, 3 sessions/week, 60-second interval and intensity of 50% to 100% ML, an overload of 30 g was added up to the 5th set; RT3: RT protocol with 4 to 5 climbs, 5 sessions/week, 60-second interval and intensity of 50% to 100% ML; when the 4th set was performed, the animals underwent the 5th climb with 100% + 30 g. IMLT: initial maximum load test; FMLT: final maximum load test. * $p < 0.05$ versus C; # (RT3 versus RT1). One-way ANOVA followed by Bonferroni post-hoc test.

Figure 1. Strength performance of the groups in the initial and final Maximum Load Tests (MLT).

Table 2. Cardiac and musculoskeletal morphological characteristics.

	Groups			
Variables	**C**	**RT1**	**RT2**	**RT3**
Heart (g)	1.09 ± 0.14	1.09 ± 0.15	0.99 ± 0.20	1.12 ± 0.19
LV (g)	0.75 ± 0.10	0.78 ± 0.11	0.70 ± 0.15	0.80 ± 0.13
RV (g)	0.24 ± 0.05	0.23 ± 0.05	0.21 ± 0.05	0.22 ± 0.06
AT (g)	0.10 ± 0.03	0.08 ± 0.02	0.08 ± 0.02	0.10 ± 0.02
Heart/Tibia (g/cm)	0.27 ± 0.03	0.27 ± 0.03	0.26 ± 0.04	0.28 ± 0.04
LV/Tibia (g/cm)	0.19 ± 0.02	0.19 ± 0.02	0.18 ± 0.03	0.20 ± 0.02
RV/Tibia (g/cm)	0.06 ± 0.01	0.06 ± 0.01	0.05 ± 0.01	0.05 ± 0.01
AT/Tibia (g/cm)	0.024 ± 0.008	0.020 ± 0.004	0.022 ± 0.005	0.023 ± 0.005
Biceps (g)	0.26 ± 0.05	0.26 ± 0.03	0.25 ± 0.05	0.26 ± 0.04
Soleus (g)	0.18 ± 0.03	0.18 ± 0.02	0.17 ± 0.03	0.18 ± 0.03
Plantaris (g)	0.38 ± 0.06	0.38 ± 0.04	0.39 ± 0.05	0.45 ± 0.08
Biceps/Tibia (g/cm)	0.07 ± 0.01	0.06 ± 0.01	0.06 ± 0.01	0.07 ± 0.01
Soleus/Tibia (g/cm)	0.045 ± 0.008	0.043 ± 0.004	0.043 ± 0.007	0.045 ± 0.007
Plantaris/Tibia (g/cm)	0.095 ± 0.014	0.094 ± 0.009	0.100 ± 0.013	0.11 ± 0.020

Values expressed in mean ± standard deviation. 7 animals per experimental group. n: total number of animals. C: sedentary control group; RT1: RT protocol with 4 to 9 climbs, 3 sessions/week, 2-minute interval and intensity of 50% to 100% of the maximum load (ML); an overload of 30 g was added up to the 9th set; RT2: RT protocol with 4 to 5 climbs, 3 sessions/week, 60-second interval and intensity of 50% to 100% ML; an overload of 30 g was added up to the 5th set; RT3: RT protocol with 4 to 5 climbs, 5 sessions/week, 60-second interval and intensity of 50% to 100% ML; when the 4th set was performed, the animals underwent the 5th climb with 100% + 30 g. LV: left ventricle; RV: right ventricle; AT: atrium. One-way ANOVA, supplemented by Bonferroni post-hoc test.



Number of animals per group = 7. C: sedentary control group; RT1: RT protocol with 4 to 9 climbs, 3 sessions/week, 2-minute interval and intensity of 50% to 100% of the maximum load (ML); an overload of 30 g was added up to the 9th set ; RT2: RT protocol with 4 to 5 climbs, 3 sessions/week, 60-second interval and intensity of 50% to 100% ML; an overload of 30 g was added up to the 5th set; RT3: RT protocol with 4 to 5 climbs, 5 sessions/week, 60-second interval and intensity of 50% to 100% ML; when the 4th set was performed, the animals underwent the 5th climb with 100% + 30 g. A) LV histological sections stained with hematoxylin and eosin for measurement of the myocyte Cross-sectional Area (CSA). B) LV histological sections stained with picrosirius red for measurement of myocardial collagen; C) Histological sections of the biceps stained with hematoxylin and eosin for measurement of musculoskeletal CSA. Two-way ANOVA supplemented by Bonferroni post-hoc test.

Figure 2. Values expressed in mean ± standard deviation.

The RT protocols used in this particular study did not entail changes in body adiposity. In actual fact, studies with humans using RT without a prescribed calorie-restricted diet indicate that this tool alone is not able to promote significant reductions in body weight.[19,20] In addition, changes in body composition with isolated RT have controversial results, while some studies have observed a reduction in body fat,[21] others have not found any changes in this parameter.[22]

Leite et al,[7] using the same ladder training protocol with adult Wistar rats, observed positive changes in the body composition of the animals visualized by the reduction of fat percentage in the RT group, even in the absence of changes in body weight. Furthermore, some studies in humans have also failed to observe weight and body fat reductions with RT. Willis et al[22] evaluated the effect of aerobic and resistance training, as well as the combination of training methods, on the body composition of 119 overweight or obese sedentary adults trained for a period of eight months. The findings show that resistance training alone caused an increase in body mass with a slight increase in lean mass, but without reductions in fat mass and waist circumference. However, sedentary individuals produced an increase in fat mass and fat percentage without changes in lean mass.[23] Given this context, the absence of weight loss and body fat with the ladder protocol designed for animal studies is similar to the response to non-calorie restricted RT practiced by humans.

Regarding strength performance, we were able to note that the animals carried a similar absolute load in the IMLT, which is consistent with the findings of other researchers.[10,24] This result shows that the experimental groups were homogeneous in terms of strength production, with no significant differences in the pre-training period. After the end of the training and retest protocol, the groups that underwent RT had a greater strength gain than the sedentary group. The literature emphasizes that strength gain is directed by neural and/or structural adaptations that occur in skeletal muscle,[25] which are evidenced by the development of intra and intermuscular coordination, with consequent greater fiber recruitment or visualized by the increase in the cross-sectional area and number of myofibrils.[25] It is extensively acknowledged in literature that regular exercise is able to improve muscle strength and physical fitness, resulting in improved functional capacity.[26]

Experimental research using the ladder model has found that the protocol is effective in inducing lower[27] and upper limb[28] muscle hypertrophy, yet other studies have failed to observe these structural adaptations.[29] Compared to other animal models of overload for the purpose of inducing skeletal muscle hypertrophy, such as tenotomy or surgical ablation, the ladder model may not be the most suitable due to its controversial results. In this particular study, none of the RT protocols managed to actually bring about morphological changes in the upper and lower limb muscles. In addition, the cross-sectional area of the biceps did not present structural changes caused by the different interventions with RT, indicating that the protocols failed to induce skeletal muscle hypertrophy.

Regardless of the changes in muscle mass, the ladder training protocol is also expected to entail neuromuscular adaptations.[29] Authors report that RT causes neuromuscular junction remodeling, as well as increased dispersion of acetylcholine receptors within the terminal plate region, but no changes in muscle fiber size after this intervention.[29] In this particular study, the greater strength gains of the trained groups in comparison to the sedentary group, even with the absence of muscle hypertrophy, suggest that these adaptations were the main determinants of the increase in muscle strength.

It is worth emphasizing that gain in muscle strength was also observed when normalizing the load carried by the animal's body weight (relative load). In the IMLT, the groups had the same functional capacity.

However, after the different RT protocols, we noticed that the trained groups achieved greater functionality compared to the sedentary group, indicating that the strength gain and body weight of these groups increased progressively during the experimental period. In the sedentary group, there was a reduction in relative load over time, probably because of physical inactivity. On the other hand, authors point out that strength production capacity is related to physical functionality, and that the latter depends on changes in body composition.[30]

Regarding the adaptations in cardiac tissue, the different RT protocols did not promote macroscopic and/or microscopic remodeling. The frequently observed adaptations in the myocardium promoted by physical exercise are eccentric and/or concentric cardiac hypertrophy. However, physiological adaptation is dependent on the type of training, duration and intensity. The literature also indicates that in RT, concentric cardiac remodeling usually occurs as of afterload elevation. Thus, there is an increase in LV wall thickness and a reduction in the cavitary diameters, vizualized by the synthesis of sarcomeres in parallel.[16] In view of this context, in our investigation we expected the animals undergoing RT on a ladder to have physiological cardiac remodeling, since the addition of sarcomeres in serie allows the cell to increase in length and the number of myofibrils, allowing the improvement of cardiac performance.[16]

CONCLUSION

Resistance training protocols on a vertical ladder, regardless of weekly frequency, entail increased muscle strength without cardiac and skeletal structural adaptations.

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All authors declare no potential conflict of interest related to this article

AUTHORS' CONTRIBUTIONS: Each author made significant individual contributions to this manuscript. APLD, LCC, ABM and CDEC: participated in the development of the research and in the experimental protocol; WME: prepared the heart tissue slides; LCC: prepared and analyzed the skeletal muscle slides; BVN: analyzed the heart tissue slides and discussed the histological results; APLD, LCC and CDEC: wrote this article; LGF, APLL and ASL: monitored and provided guidance on all the experimental procedures conducted, participated in the writing and final review of the article. APLD, LCC and ABM: also contributed to the production of the article. All authors reviewed and approved the final version of the manuscript

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